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COMMON GROUND 07

Residential development in a landslide area in Sydney

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ABSTRACT

The Soil Conservation Service of New South Wales indicates that slope instability imposes limitations on residential development in Glen Road, Castle Hill, Sydney. Geotechnical investigation indicates three distinct types of subsurface profiles across the site arbitrarily defined as Profile 1, Profile 2 and Profile 3. Polished and slickensided slip surfaces were observed in Profile 1 and Profile 2. Inclinometer measurements show ground movements along these slip surfaces. No slip surfaces were observed in Profile 3. Slope stability analysis indicates that the portions of site within Profiles 1 and Profile 2 have very high risk of slope instability and hence in their existing condition these are not suitable for residential development. Back analysis was carried out to assess the strength characteristics of materials along the slip surfaces and the groundwater levels, which could trigger slope movements. The risk of slope instability in Profile 3 is acceptable for residential development. This paper presents results of the geotechnical investigation and slope stability analysis and provides recommendations for appropriate site preparation and/or remediation methods to make entire site suitable for residential development. The stabilization works include one or a combination of sub-soil drainage, installation of engineered retaining structures and removal of unstable portions of the site with replacement by controlled fill.

1 INTRODUCTION

A site in Glen Road at Castle Hill, Sydney, is to be subdivided into six residential lots, each measuring approximately 2000m^2 in area, with a community title access road. The Urban Capability Study of the West Pennant Hills Area (Soil Conservation Service of New South Wales, 1977) indicates that slope instability imposes limitations on residential development of the site. Therefore, geotechnical investigation and slope stability analysis have been carried out to assess the risk of slope instability and to ascertain if the site can be developed for residential purposes. This paper presents results of the geotechnical investigation and slope stability assessment and provides recommendations on appropriate site remediation works to make the site suitable for residential subdivision.

2 SITE DESCRIPTION

2.1 Site features

The site is located on the western side of Glen Road cul-de-sac, Castle Hill, and covers an area of approximately 1.4 hectares. Ground surface within the site generally dips towards the south, with overall slopes in the order of about 8 degrees in the southern portion, 10 degrees in the central portion and 15 degrees in the northern portion. Locally ground slopes are as steep as 20 to 25 degrees. There are numerous areas with a bulging or hummocky surface.

Residential lots to the north of the site show signs of ground movement, but properties to the east and south show no obvious signs of instability. The western neighbouring property has similar site features to those within the site.

2.2 Subsurface conditions

The site is underlain by Middle Triassic Age Bringelly Shale and Ashfield Shale (Herbert, 1980). The three distinct sub-surface profiles across the site are arbitrarily defined as Profile 1, Profile 2 and Profile 3 (Geotechnique Pty Ltd, 2006). The approximate boundaries between profiles areas are indicated in Figure 1 with the subsurface profiles along Sections AA and BB shown in Figures 2 and 3.

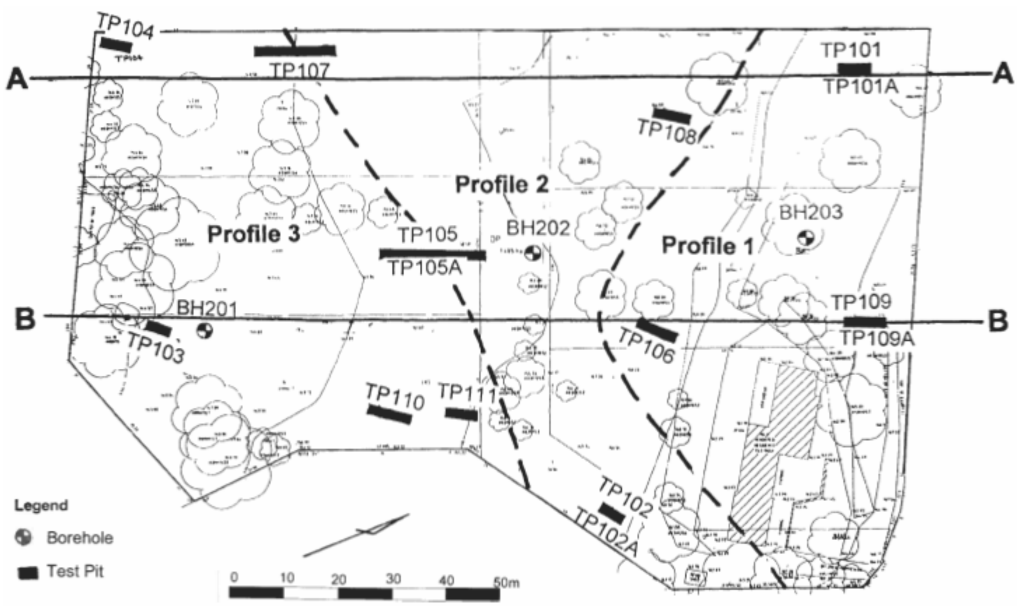

Figure 1: Plan showing locations of boreholes and test pits and three types of subsurface profiles

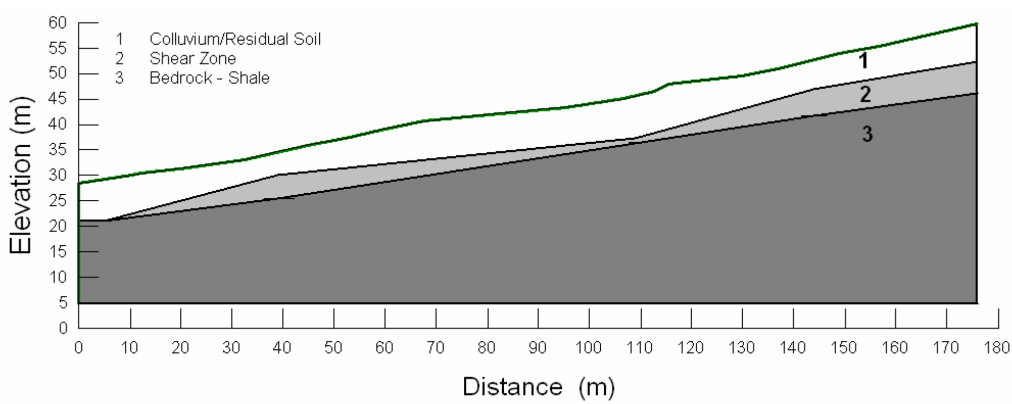

Figure 2: Cross Section AA (Distance measured from the Southern Boundary)

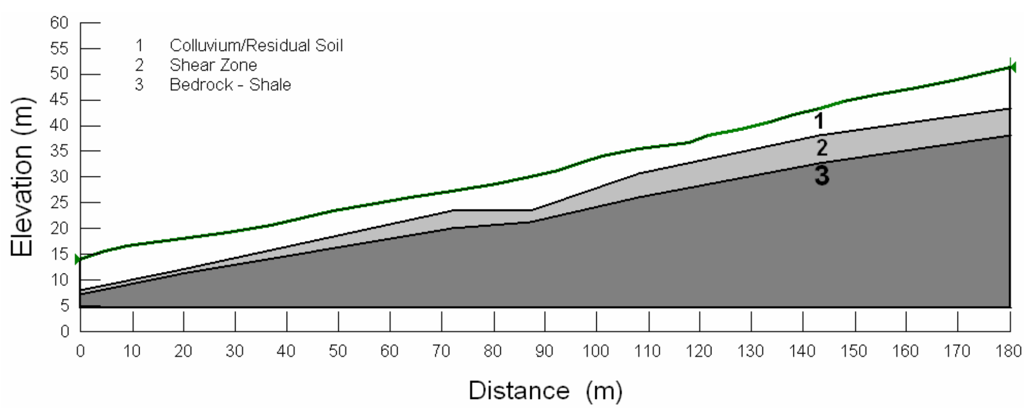

Figure 3: Cross Section BB (Distance measured from the Southern Boundary)

The sequence of materials in three profile types are presented in Table 1.

Table 1: Types of subsurface profiles

Material Types	Depth from Existing Ground Surface		
	Profile 1	Profile 2	Profile 3
Topsoil - Silty Clay	Up to 0.3m to 0.6m	Up to 0.3m to 0.7m	Up to 0.3m to 0.5m
Colluvium - Gravelly Clay, medium to high plasticity, with pockets of randomly oriented gravels	Up to 7.1m to 7.9m	Not Encountered	Not Encountered
Residual Soil - Clay, Gravelly Clay, medium to high plasticity, with some gravels	Not Encountered	Up to 5.4m to 6.2m	Up to 4.5m to 6.0m
Bedrock - Shale	>7.1m	>5.4m	>4.5m

Bedrock shale is extremely or distinctly weathered up to depth of 7.0m and then becomes slightly weathered or fresh. Sliding planes were observed in Profile 1 and 2 but not in Profile 3. Sliding planes comprised polished or slickenside surfaces, within soft and high plasticity clay, generally about 100mm thick. Slip surfaces dipped approximately at 15 - 20 degrees towards the south.

2.3 Groundwater conditions

Groundwater levels in three standpipes (see Figure 1) and rainfall in North Parramatta (nearest meteorological station located at distance of about 8.0km from the site) as obtained from the Bureau of Meteorology web site (2006) are presented below in Table 2.

Table 2: Groundwater level and rainfall

Measurement Dates	Cumulative Rainfall in Preceding Week (mm)	Depths to Groundwater Levels in Standpipes from Existing Ground Surface (m)		
		BH201	BH202	BH203
21/04/04	0.0	Not Measured	2.9	5.6
04/08/04	0.8	4.8	3.5	4.8
02/11/04*	4.3	3.5	0.6	3.5
04/11/04*	4.3	4.9	1.8	4.7
16/12/04	43.9	3.6	2.3	4.3
24/1/05	44.0	3.5	2.6	4.0
4/3/05	6.3	3.6	2.7	3.9
3/11/05	39.7	4.2	2.7	3.7

Note: *Groundwater was pumped out after measurement on 2 November 2004

Rainfall and groundwater levels do not show any distinct relationships. This could be because of the significant distance between standpipes and the rain gauge and/or delay in groundwater response to rainfall due to the clayey soil profile.

3 INCLINOMETER READING

Inclinometers installed in three boreholes BH201, BH202 and BH203 were monitored first on 21 April 2004 and subsequently on 4 August 2004, 4 November 2004, 4 March 2005 and 2 November 2005 (Geotechnique Pty Ltd, 2006). Results of the inclinometer readings are summarised below:

- BH201 indicates that the sub-surface profile is undergoing downslope movement of about 3.0mm within the upper 1.5m of profile. However, movement below depth of 1.5m and cross movement are less than about 1.0mm.
- BH202 indicates that the sub-surface profile is undergoing downslope movement of about 2.0mm within the upper 3.0m. The soil movement within depths of 3.5m to 6.0m is about 1.0mm. Cross-slope movement is approximately 4.0mm towards the east.
- BH203 indicates that the sub-surface profile is undergoing downslope movement of about 4.0mm within the upper 5.0m. Movement below depth of 5.0m and cross movement are less than about 1.0mm.

Only BH203 displays continued displacement to positively confirm ground movements and the depth of the sliding plane. Small erratic slope movements in other locations could also be related to reactivity of the clays rather than to slope stability issues.

4 LABORATORY TEST

Large Direct Shear tests were conducted on natural and lime stabilised (5% by weight) soil samples compacted to dry density ratio of 95% to 98% standard, at about optimum moisture content. Samples were submerged and consolidated under normal stresses between 50kPa and 200kPa and then sheared at rate of 0.02mm/minute. Based on laboratory tests on four natural and four lime stabilised samples and considering likely influences from test methods, indicative effective peak strength parameters of compacted natural soils are estimated to be a cohesion of 15kPa to 40kPa and friction angle of 25 - 30 degrees. The corresponding residual strength parameters are 0kPa to 5kPa and 10 - 15 degrees respectively. The strength parameters for lime stabilised soil samples are only marginally higher than those for natural soil.

5 SLOPE STABILITY ANALYSIS

5.1 Qualitative risk of slope instability

Applying "Landslide Risk Management Concepts and Guidelines" (Australian Geomechanics Society, 2000), the site can be divided into two areas in terms of risk of instability, as indicated in Table 3.

Table 3 : Qualitative risk of slope instability

Qualitative Measures	Profiles 1 and Profile 2	Profile 3
Likelihood of Landslides	**Almost Certain:** The event is expected to occur ($\approx 10^{-1}$)	**Possible:** The event could occur under adverse conditions ($\approx 10^{-3}$)
Consequences of Landslides to Property	**Major:** Extensive damage to most of structures or extending beyond site boundaries requiring significant stabilisation works	**Medium:** Moderate damage to some of structures, or significant part of site requiring large stabilisation works
Qualitative Risk to Property	**Very High**	**Moderate**

5.2 Back analysis

The subsurface profiles across the site comprise a sequence of colluvium, residual soil underlain by shear zone and bedrock. Estimates of effective strength parameters for colluvium/residual soil and bedrock are presented in Table 4.

Table 4 : Effective strength parameters for natural soil and bedrock

Soil/Rock Description	Peak Strength Parameters			Residual Strength Parameters		
	Unit Weight (kN/m^3)	Cohesion (kPa)	Friction Angle (degree)	Unit Weight (kN/m^3)	Cohesion (kPa)	Friction Angle (degree)
Colluvium/Residual Soil	17.0	0.0 - 5.0	15.0	17.0	0.0	10.0
Bedrock - Shale	20.0	15.0	30.0	Not Applicable		

For strength parameters presented in Table 4 and varying groundwater level, the estimates of effective strength parameters for shear zones in Sections AA and BB to achieve a factor of safety of 1.0 (Back Analysis) are presented in Table 5.

Table 5 : Estimated effective strength parameters for shear zone

Depth to Groundwater Level (m)	Strength Parameters for Shear Zone to achieve Factor of Safety =1			
	Section AA		Section BB	
	Cohesion (kPa)	Friction Angle (degree)	Cohesion (kPa)	Friction Angle (degree)
1.0	0.0	14	0.0	16
2.0	0.0	10	0.0	12
3.0	0.0	8	0.0	10

Table 5 indicates slope movements are likely to be initiated when groundwater level is within 3.0m of existing ground surface, when the strength of shear zone materials is represented by effective cohesion of 0.0kPa and effective friction angle of 8 - 10 degrees. During the monitoring period, groundwater level was recorded within depth of 1.0m.

Back analysis also indicates that a Factor of Safety of about 1.4 can be achieved for residual strength parameter, if groundwater level is lower than the slip surfaces. This means the risk of slope instability is moderate if groundwater level is permanently lowered below sliding planes.

6 REMEDIAL WORKS

Back analyses indicate that the risk of slope instability for the existing slope profile is unacceptable for residential subdivision. Therefore, appropriate remediation works, detailed below, should be implemented to reduce the risk and make the site suitable for residential development.

6.1 Profile 3

Profile 3 is suitable for residential development provided all building slabs are fully suspended and supported by deep footings (piers) socketed into bedrock. Although no evidence of ground movement was observed care should be taken to ensure landslides are not induced by construction activities. If shallow footings are desired, following remedial works are recommended.

- Strip sliding materials to expose stable natural materials. Stripping should be carried out first in the eastern half and excavated material spread over the western half.
- The cut/fill faces should be battered at about 1 vertical to 1 horizontal for temporary stability.
- Stabilise the excavated materials with 2% of hydrated lime and replace on the exposed natural soil in the eastern half in a controlled manner. Lime is to improve shrink swell properties.
- Repeat excavation, mixing and replacement of excavated soils in the western half as above.

6.2 Profile 1 and 2

Profiles 1 and 2 have been and are still subject to landslides. Remedial works for these profiles include the following.

6.2.1 Sub-surface drainage

Sub-surface drainage should be installed to lower the groundwater level, and may comprise single graded aggregate of 20mm or 40mm size, wrapped in non-woven geofabric, or equivalent materials, installed in a trench excavated to depth of at least 0.5m into stable bedrock. Sub-surface drainage trench should intersect all slip surfaces.

Sub-surface drainage should be designed for 1 in 100 year rainfall events. It is anticipated that sub-surface drainage installed at distance intervals of about 15m – 20 m in the north-south direction, with lateral catch drains at intervals of about 5m – 10 m would be adequate to lower groundwater level below shear zone.

6.2.2 Retaining structures

The northern neighbouring properties are showing signs of movement and no stabilisation works are likely to be carried out in these properties. Therefore, retaining structures should be installed along the northern site boundaries before any excavation works are carried out within the site. Appropriate retaining structures will comprise anchored contiguous piles or soldier piles founded, socketed and anchored into bedrock.

6.2.3 Remove and replace sliding materials

Installation of sub-surface drainage and retaining structures will reduce the risk of instability. However, continual monitoring will be required to confirm the success of drainage installation. Therefore, sliding materials should be removed and replaced with controlled fill as follows:

- Excavate sliding materials in Profile 1 and spread to uniform thickness across Profile 3. The excavation should be carried out from the north to the south in about 15 m wide strips. Excavation faces should be retained or battered at about 1 vertical to 1 horizontal for short term stability.
- Install sub-surface drainage. It is preferable that sub-surface drainage is installed before excavation and that replacement work is commenced if groundwater level is shallower than the sliding surface.
- Mix the excavated materials with 2% of hydrated lime and replace on the exposed bedrock in a controlled manner.
- Once all unstable material in Profile 1 is removed and replaced with controlled fill in about 6 - 7 strips, the same method can be repeated for Profile 2.

7 CONCLUSIONS

Slope stability analyses for every stage of the remedial work indicate that the risk of slope instability is acceptable for most portions of the site (Factor of Safety exceeding 1. 5), except slopes along the eastern and western boundaries, where the Factor of Safety is in the range of 1.1 to 1.3. Therefore, removal and replacement of the materials should be carried out as fast as possible.

At the completion of recommended remediation works the Factors of Safety against sliding are 1.3 to 1.5 and 1.5 to 2.1 when groundwater level is within 1 m and 3 m from existing ground surface respectively. Therefore the risk of slope instability across the site will be reduced to "low", which is considered to be acceptable for residential development provided that the drainage system is maintained properly so that groundwater level does not rise within 3 m from the existing ground surface.

8 REFERENCES

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